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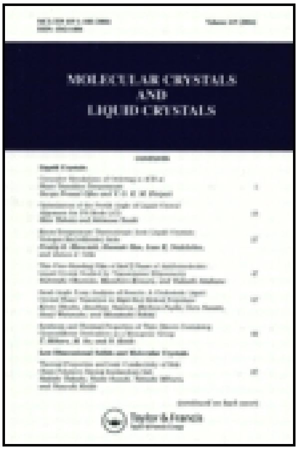

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Alignment Capabilities and EO Performances of VA-LCD Using Transparent Conductive Al-doped ZnO Films

Sang-Hoon Kim [a], Jeoung-Yeon Hwang [a], Jong-Hwan Kim [a], Young-Hwan Kim [a], Dong-Hun Kang [a], Sang-Keuk Lee [a], Jin-Woo Han [a], Chul-Ho Ok [a], Dae-Shik Seo [a] & Eung-Sang Kim [b]

[a] Department of Electrical & Electronic Engineering, College of Engineering, Yonsei University, Sudaemoon-gu, Seoul, Korea

[b] Department of Renewable Energy Group, KERI, Changwon City, Korea

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Sang-Keuk Lee
Jin-Woo Han
Chul-Ho Ok
Dae-Shik Seo
Department of Electrical & Electronic Engineering, College of Engineering, Yonsei University, Sudaemoon-gu, Seoul, Korea

Eung-Sang Kim
Department of Renewable Energy Group, KERI, Changwon City, Korea

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Transparent electrodes are indispensable for most of the flat panel display as liquid crystal display (LCD). We investigated liquid crystal (LC) aligning capabilities and electro-optical (EO) characteristics of transparent electrodes as Al-doped ZnO (ZnO:Al) substituting indium tin oxide (ITO). The experiment results show that a uniform vertical LC alignment on ZnO:Al electrodes based on a rubbed polyimide (PI) surface were achieved. A high pretilt angle of about 88° was obtained. EO performances of the VA-LCD on rubbed PI surfaces with ZnO:Al is almost the same as that of the VA-LCD with ITO electrodes. These results appeared that ZnO:Al electrodes as transparent electrodes of LCDs could substitute ITO electrodes.

Keywords: ITO; NLC; polyimide; rubbing; transparent conducting oxides; vertical alignment; ZnO:Al

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Address correspondence to Dae-Shik Seo, Department of Electrical and Electronic Engineering, Yonsei University Shinchon-dong, Sudaemoon-gu, Seoul 120-749, Korea (ROK). E-mail: dsseo@yonsei.ac.kr.

INTRODUCTION

Transparent electrodes are indispensable for most of the flat panel display (FPD) as liquid crystal display (LCD). Nowadays, transparent conductive oxide films, based on indium tin oxide (ITO) have been widely applied to FPD such as LCDs and organic lightemitting diodes (OLEDs) due to low electrical resistivity and high optical transparency [1–3]. However small amount of indium deposits increases production costs gradually [4–6] and ITO film is unstable in the hydrogen plasma atmosphere in the fabrication process. Currently, Al-doped ZnO (ZnO:Al) film is regarded as an attractive candidate for transparent conductive oxides due to low resistivity, high transparency, high thermal stability, and relatively low cost [7]. Nowadays, the vertical alignment (VA) mode is one of the most using LCD mode. The major advantages of the VA-LCD over the other mode are the much wider viewing angle, a uniform gray scale and reduced color shift [8–12]. Previously, VA characteristics of the nematic liquid crystal (NLC) on the various treated substrates have been reported [13–17].

In this study, we invesgated the feasibility of applying ZnO:Al films to display device as transparent electrode, and reported the electro-optical characteristics of VA-LCD cell using ZnO:Al electrodes as compared with ITO electrodes.

EXPERIMENTAL

ZnO:Al and ITO electrodes deposited on glass, which was made up for Samsung corning Co. LTD were used in this experiment. The glass substrates were first cleaned with standard cleaning procedures (TCE-acetone-methanol) and then rinsed in deionized water. ZnO:Al electrodes were prepared by rf magnetron co-sputtering method. ITO electrode deposited also prepared for comparative study. The schematic diagram of sputter system is shown in Figure 1.

Details of experiment conditions have been reported elsewhere [18]. Electrical and optical properties of these films are summarized in Table 1. Polyimide (PI) was uniformly coated with the thickness of 500 nm on ZnO:Al and ITO electrodes using a spin-coating method. The PI layers on ZnO:Al and ITO electrodes were imidized at 140°C for 1 hr and then the surfaces of the PI layers were rubbed by rubbing machine. After rubbing, two samples were filled with a NLC ($T_c = 75°C$, $\Delta n = 0.077$, $\Delta\varepsilon = 8.2$) for VA test. The thickness of the liquid crystal cells for VA-mode and pretilt test samples were 4 μm and 60 μm, respectively. The pretilt angle of anti-parallel cell was measured by a crystal rotation method. LC alignment effects were

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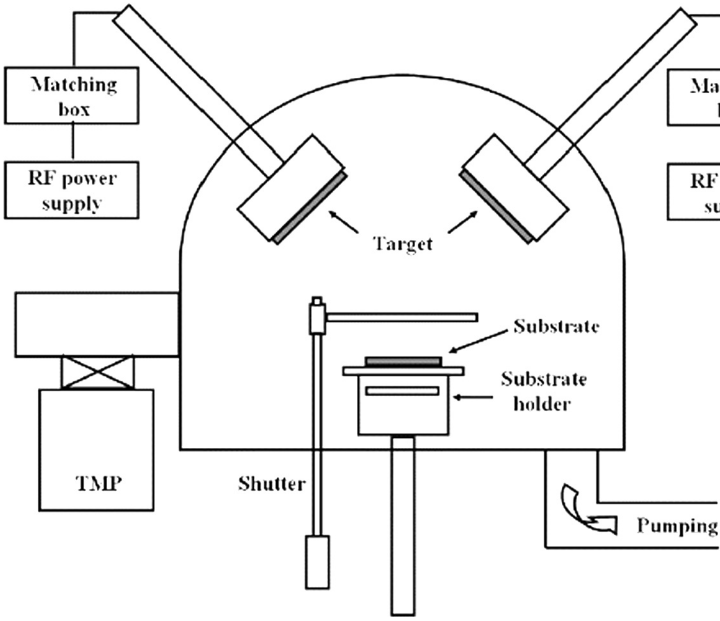

FIGURE 1 The schematic diagram of sputter system.

observed using a polarized microscope. In addition Voltage-Transmittance *(V-T)* and response time characteristics of these VA-LCDs were measured by LCMS-200 (Electro-Optical Measurement, from Sesim Photonics Technology Co. LTD) equipment. Also the residual DC voltage properties of two kinds of electrodes VA-LCDs were measured by a capacitance-voltage *(C-V)* hysteresis method (LCR meter, Agilent 4284A) at room temperature.

RESULTS AND DISCUSSION

Table 2 show the generated NLC pretilt angle as a function of rubbing strength (RS) in the LC cell using ZnO:Al and ITO electrodes. The

TABLE 1 Electric and Optical Properties of ZnO:Al and ITO Electrode Films

Material	Resistivity ($\times 10^{-3}\,\Omega$cm)	Carrier concentration ($\times 10^{21}\,cm^{-3}$)	Transparency (in visible range, %)
ZnO:Al	8.12	0.42	90.12
ITO	0.18	1.72	88.89

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TABLE 2 Generation of Pretilt Angle as the Function of Rubbing Strength

Material / Rubbing strength	ZnO:Al	ITO
0.3 mm	87.9°	88.2°
0.5 mm	86.9°	84.2°
0.7 mm	85.1°	80.1°

generated pretilt angles of the NLC in Cells using ZnO:Al electrodes are almost same as that of NLC in cells using ITO electrodes. It decreased as increasing rubbing strength, respectively.

Figure 2 show the microphotographs of rubbing aligned NLC using ZnO:Al and ITO electrodes. NLC cells using these electrodes showed

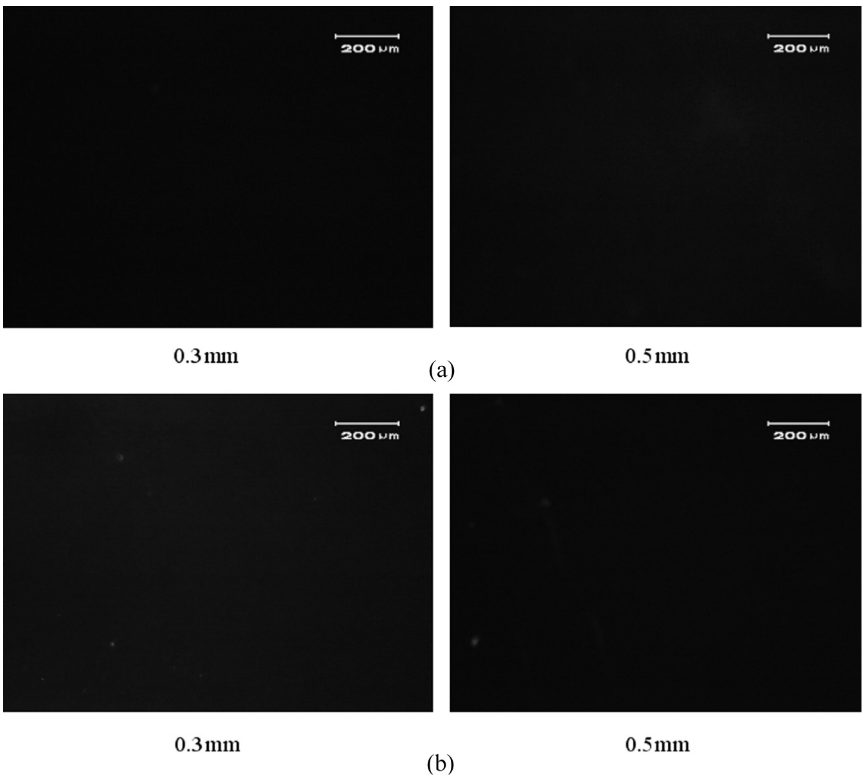

FIGURE 2 Micrographs of the rubbing aligned cells using the two kinds of transparent electrodes. (in crossed Nicols) (a) ZnO:Al, (b) ITO.

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the good alignment. Also, the LC aligning capability using ZnO:Al electrodes is the same as that using ITO electrodes.

The microphotographs show the operations of the rubbing-aligned VA-LCDs using ZnO:Al and ITO electrodes with different rubbing strength as shown in Figure 3. When the electrical field is applied to the cells (on-state), LC aligned perpendicular to the direction of the

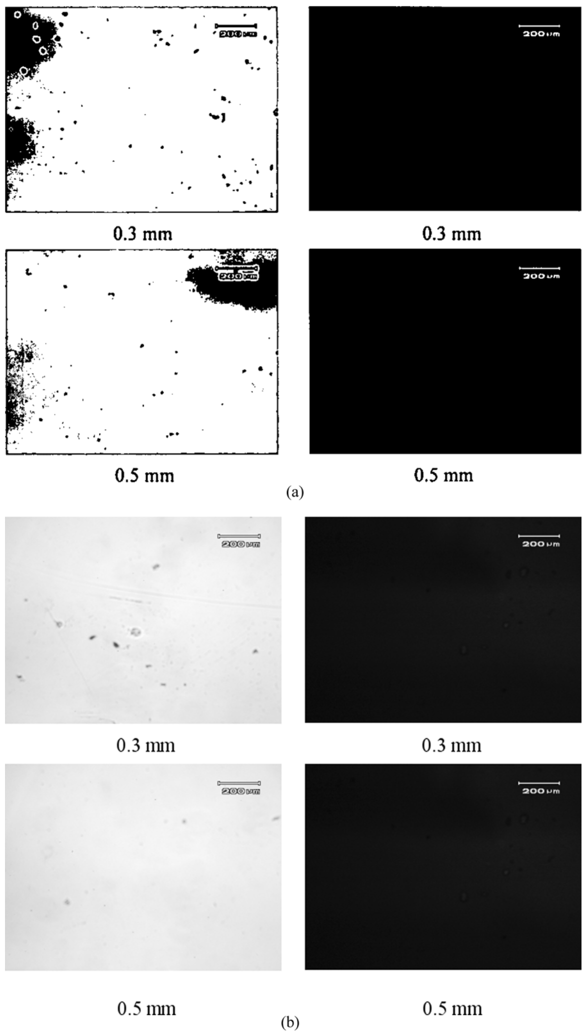

FIGURE 3 Microphotographs of VA-LCD using the two kinds of transparent electrodes. (in crossed Nicols) (a) ZnO:Al, (b) ITO.

electricfield. Thus, Liquid crystal polarized light, both the VA-LCDs clearly transmit the visible light generated from backlight units (the observed black spots in the figure are due to the spacers). In the off-state, the light transmission is prohibited resulting in dark images, which indicates the monodomain alignment of the NLC in both the VA-LCDs.

Figure 4 shows the *V-T* characteristics of both the rubbing-aligned VA-LCDs on the Zno:Al and ITO electrodes with different rubbing strength. In Figure 4(a), threshold voltages at the transmittance of 10% are 2.32 V and 2.27 V for ZnO:Al and ITO electrodes cells with rubbing strength 0.3 mm, respectively while voltages at the transmittance of 90% are 4.04 V and 3.72 V for ZnO:Al and ITO electrodes cells with rubbing strength 0.3 mm, respectively. In Figure 4(b), threshold voltages at the transmittance of 10% are 2.49 V and 2.44 V for ZnO:Al and ITO electrodes cells with rubbing strength 0.5 mm, respectively while voltages at the transmittance of 90% are 5.13 V and 4.97 V for ZnO:Al and ITO electrodes cells with rubbing strength 0.5 mm, respectively. The slopes of *V-T* curve in the transmittance range of 10 to 90% are almost identical for both the cells. It is noted that the threshold voltage of the VA-LCD with ZnO:Al electrodes is higher than that of the VA-LCD using ITO electrodes. It is relevant to the resistivity of ZnO:Al electrodes is higher than that of ITO electrodes (Table 1).

Figure 5(a) shows the response time characteristics of the rubbing-aligned VA-LCDs using ZnO:Al and ITO electrodes with rubbing strength 0.3 mm. The response time of ZnO:Al electrodes VA-LCD is 22.7 ms (rising time: 10.2 ms, decay time: 12.5 ms) while that of ITO electrodes VA-LCD is 21.5 ms (rising time: 10.0 ms, decay time: 11.5 ms). Figure 5(b) shows the response time characteristics of the rubbing-aligned VA-LCD using ZnO:Al and ITO electrodes with rubbing strength 0.5 mm. The response time of ZnO:Al electrodes VA-LCD is 21 ms (rising time: 9.8 ms, decay time: 11.2 ms) while that of ITO electrodes VA-LCD is 18.9 ms (rising time: 8.1 ms, decay time: 10.8 ms). Both cells showed fast and stable response time characteristics.

Image sticking was also very important factor for the functioning of displays. This arises from residual charges that accumulate in a local region as the voltage is left on. When the voltage is removed, the image survives and gradually fades away with time as the charge is dissipated. The capacitance-voltage *(C-V)* characteristics of the rubbing-aligned VA-LCDs using ZnO:Al and ITO electrodes with rubbing strength 0.3 mm are shown ig Figure 6(a). It can be seen that the residual DC voltage of the ZnO:Al electrode cell is 0.196 V, which is slightly smaller than the residual DC voltage of 0.275 V for ITO

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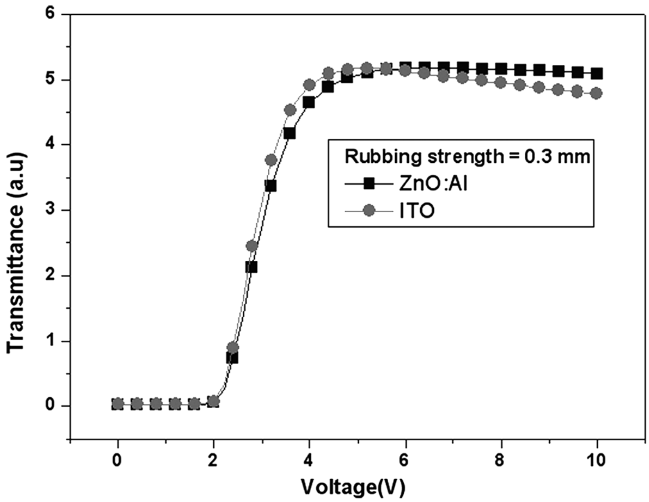
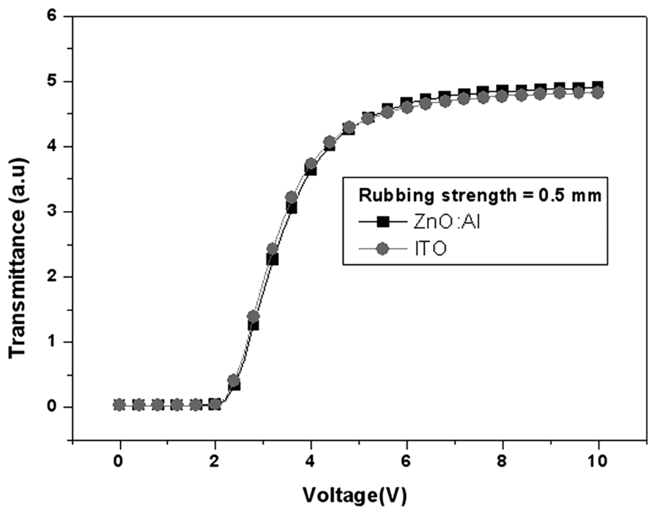


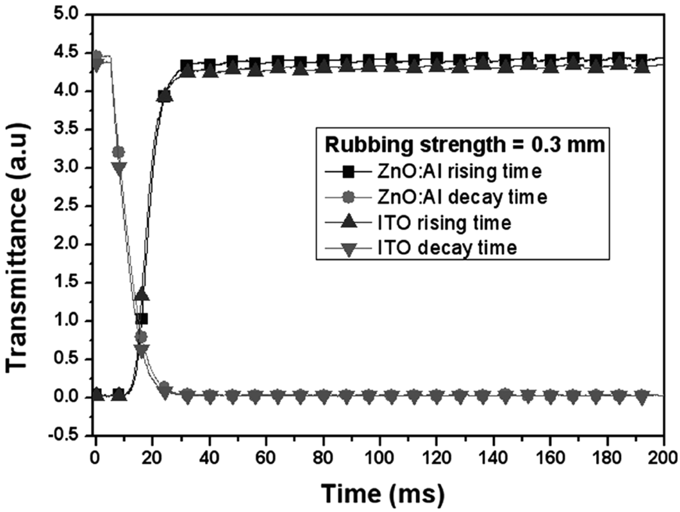
(a) RS = 0.3 mm



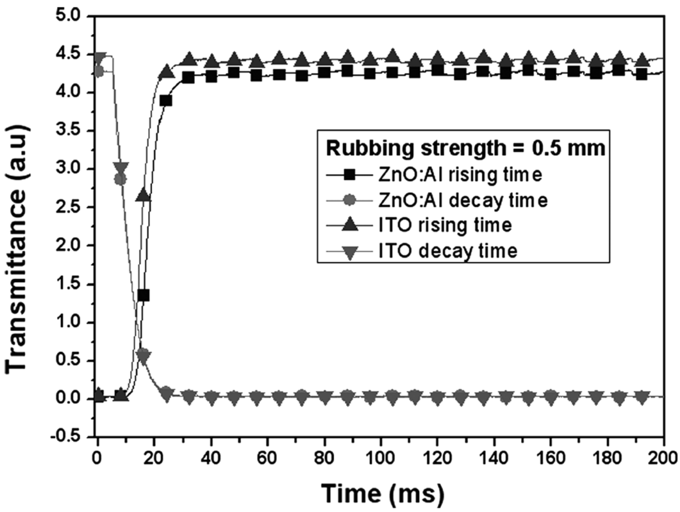
(b) RS = 0.5 mm

FIGURE 4 *V-T* curve of two kinds of VA-LCD on the rubbed PI surfaces with different transparent electrodes.

electrode cell. The measured transition voltages of ZnO:Al electrode cell and ITO electrode cell were 1.3 V and 1.303 V, respectively. In Figure 6(b), the *C-V* characteristics of the rubbing-aligned VA-LCDs using ZnO:Al and ITO electrodes with rubbing strength 0.5 mm. It



(a) RS = 0.3 mm



(b) RS = 0.5 mm

FIGURE 5 Response time characteristics of the VA-LCD on the rubbed PI surfaces with different transparent electrodes.

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can be seen that the residual DC voltage of the ZnO:Al electrode cell is 0.227 V, which is slightly smaller than the residual DC voltage of 0.333 V for ITO electrode cell. The measured transition voltages of ZnO:Al electrode cell and ITO electrode cell were 1.298 V and

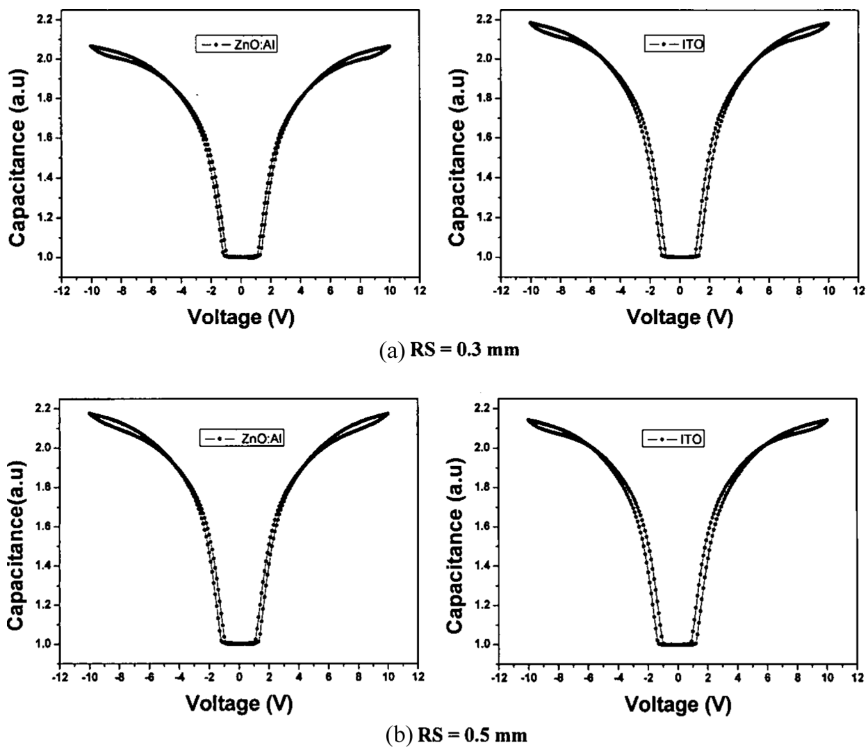

FIGURE 6 *C-V* characteristics of the VA-LCD on rubbed PI surfaces for the two kinds of transparent electrodes. (a) ZnO:Al, (b) ITO.

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1.198 V, respectively. These results indicate that there would be no image sticking in the LCDs based on ZnO:Al electrodes. It is considered that *V-T* curve, response time, *C-V* measurements could explain the improved electo-optical and residual DC characteristics of ZnO:Al based LCD cell. These results demonstrate the high application potential of ZnO:Al films as transparent electrodes of LCDs substituting ITO electrodes.

CONCLUSIONS

In this article, LC alignment effects and generation of pretilt angles with homeotropic polymer, the EO performances of the rubbing aligned VA-LCDs using ZnO:Al in comparison with ITO electrodes were studied. The VA-LCD employing ZnO:Al electrodes showed the monodomain alignment and the pretilt angle generated obtained from 85° to 88°. The good *V-T* curves were observed for the rubbing aligned VA-LCD using ZnO:Al electrodes in comparison with ITO electrodes. Also the fast response time characteristics can be achieved for the rubbing aligned VA-LCD using ZnO:Al electrodes in comparison with ITO electrodes, and the residual DC voltage of the rubbing aligned VA-LCD using ZnO:Al electrodes was good. It was found from the results that ZnO:Al electrodes as transparent electrodes of LCDs could substitute ITO electrodes.

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